Scanning Physical Interaction Behavior of 3D Objects

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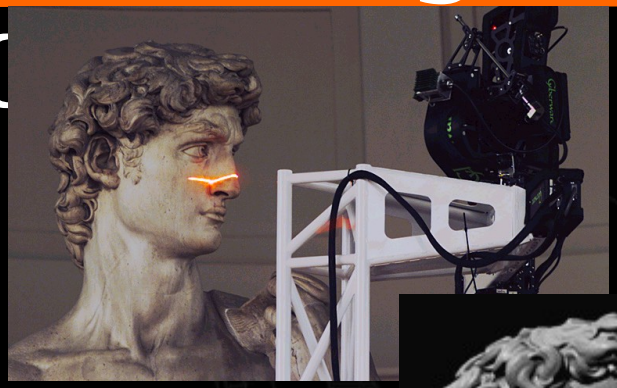
Traditional Focus of Scanning in Computer G



Stanford's
Digital Michelangelo

BRDF measurement at MPI

Geometry

Bouguet Perona 98
Curless Levoy 96
Hoppe et al 94
Levoy et al 00
Roth Wibowoo 97
Sato et al 1997
Cyberware, NRCC
...
many companies...

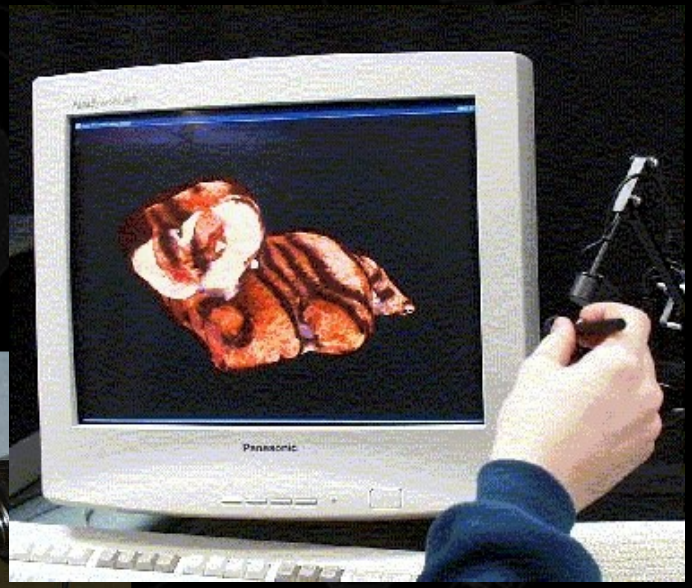
Reflectance

Dana et al 99
Debevec et al 00
Greenberg et al 97
Lensch et al 01
Rushmeier et al 98
Sato et al 1997
...

Motion capture

Popovic Witkin 99
Zordan Hodgins 99
...
very many companies...

Our Focus: Scanning Contact Interaction Behavior

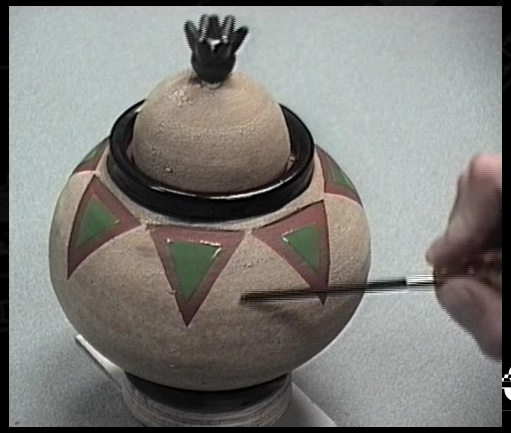


Overview

ACME, a robotic facility for scanning contact behavi

Scanning

- contact deformation models
- contact texture models
- contact sound models



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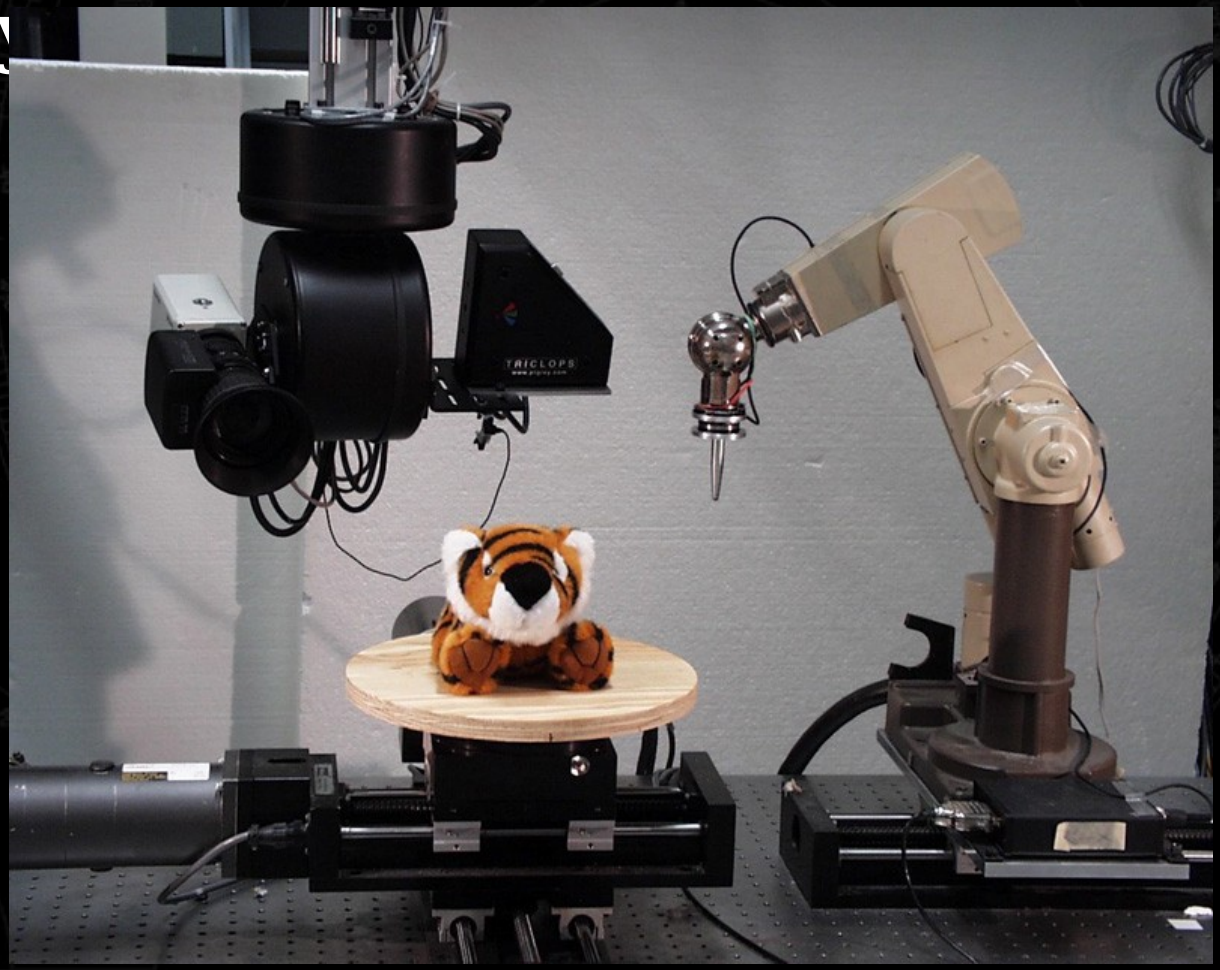
ACME

The UBC Active Measurement Facility



[Pai,Lang,Lloyd,Woodham '99]

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Preview: Scanning Contact Friction

Video

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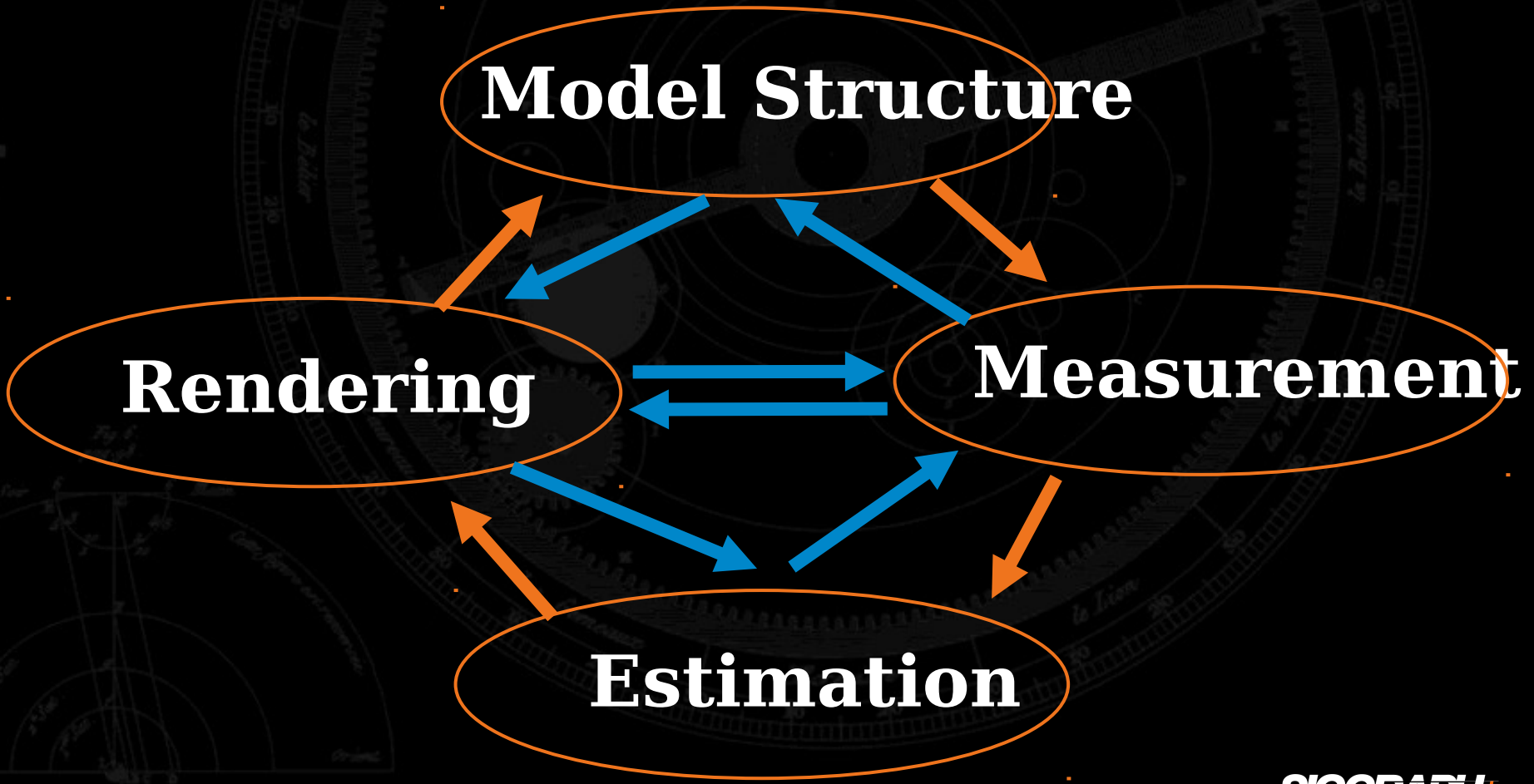
A Framework for Scanning Reality-based Models



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Scanning Deformation Behavior

Model Structure: Green's Functions

Linear Elastostatic Model

+Reference boundary conditions

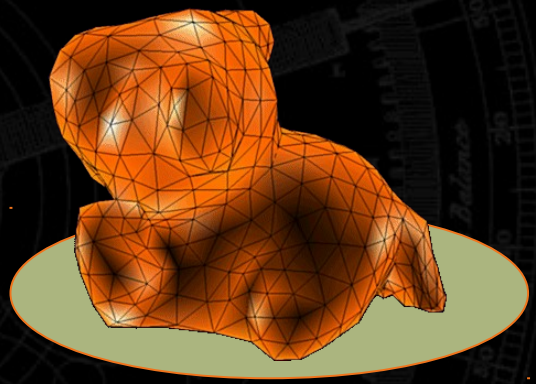
Green's functions U relate

u, vertex displacements to

p, applied vertex tractions

Can be computed analytically ***if*** material distribution is known

e.g., [JamesPai99, Cotin et al 96,...]



u = U p

Green's Functions

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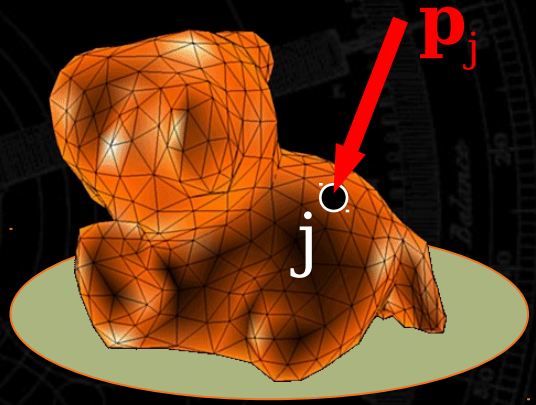
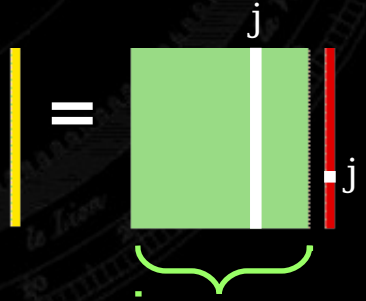


$$u = U\ p$$



Green's Functions

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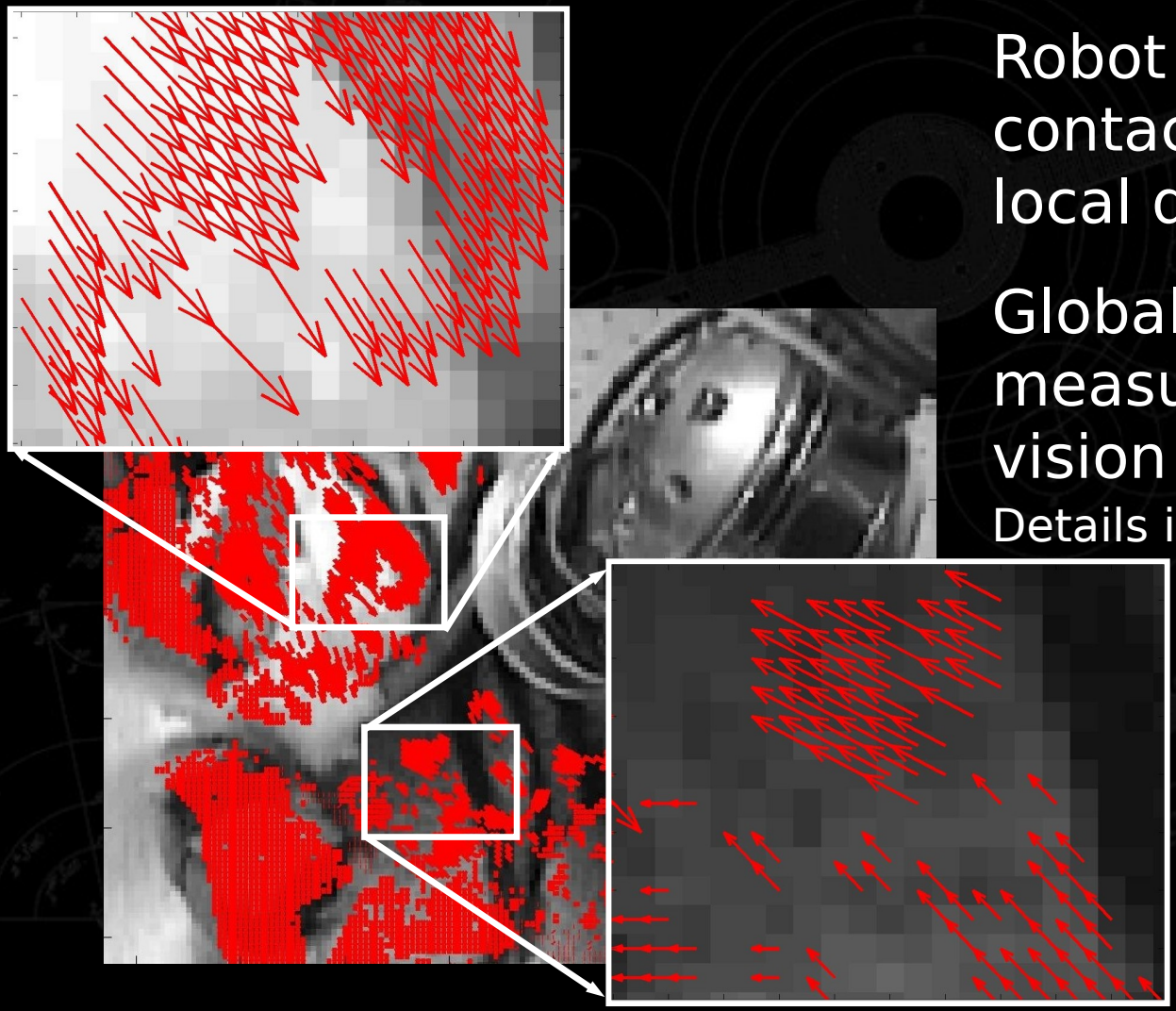
Measurement



Robot arm measures contact force and local displacement

Global displacement measured with stereo vision and range flow

Details in [LangPai01]

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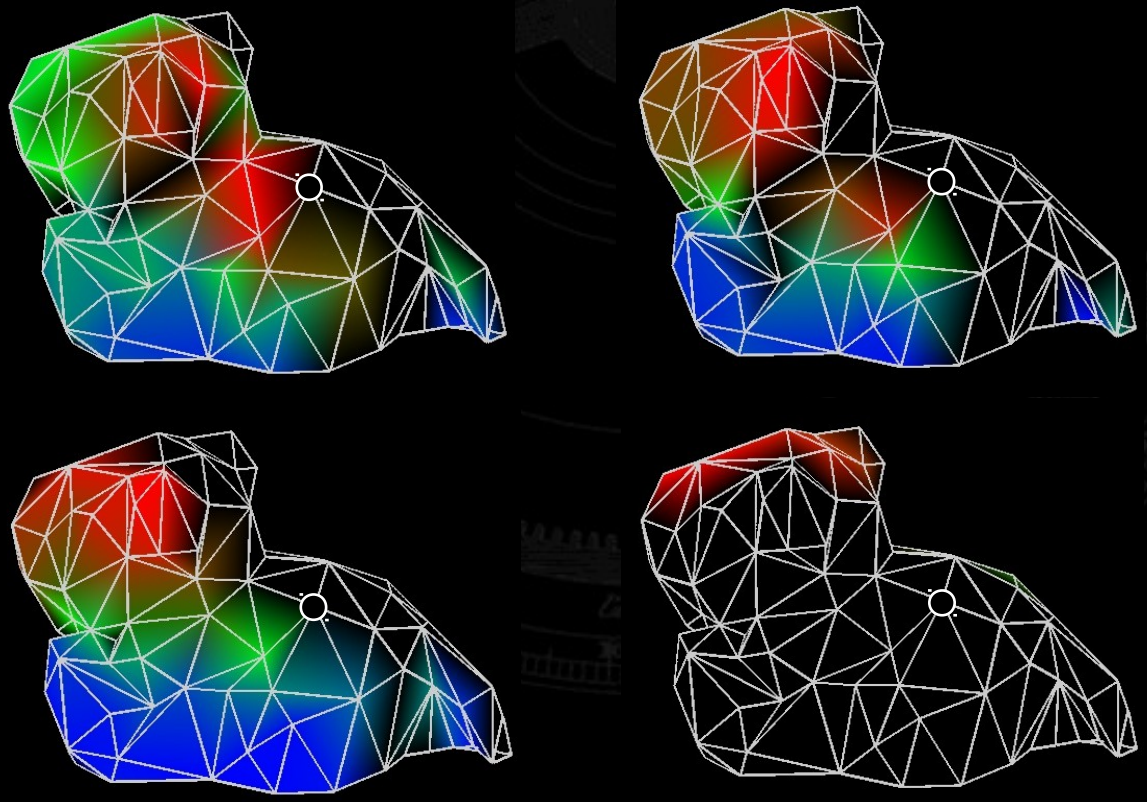
Parameter Estimation

- Excite vertex j with several p_j^k

  estimate vertex displacement u_i^k from range flow



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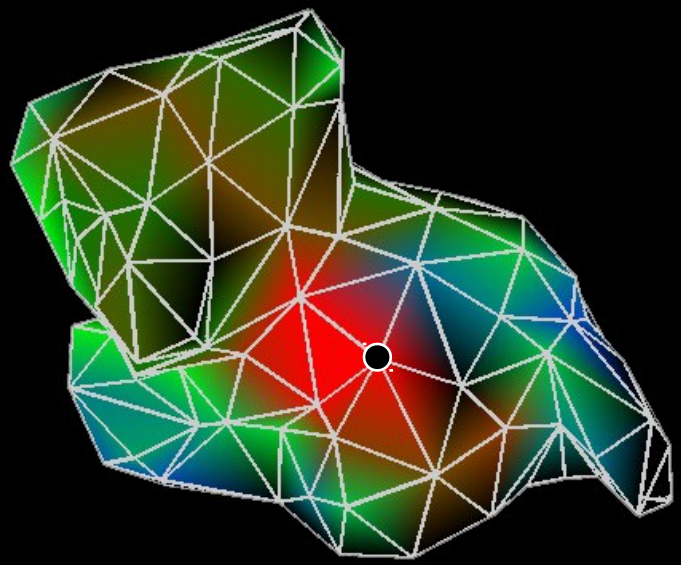
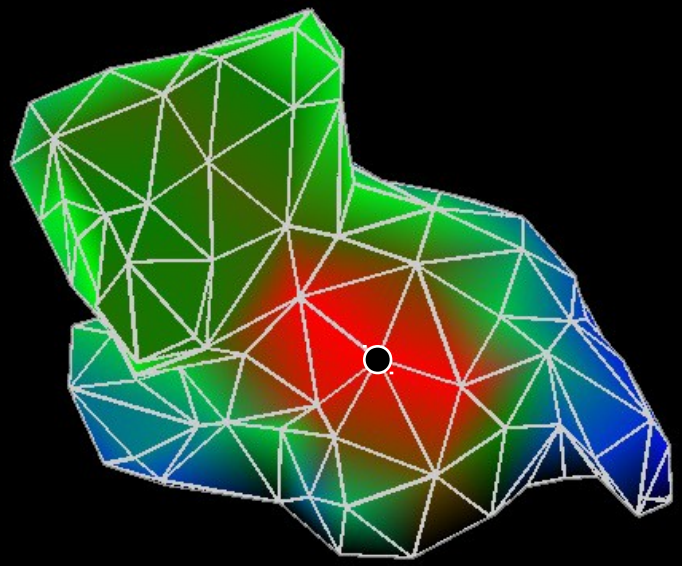
Parameter Estimation

- Estimate U_{ij} robustly using TSVD, TLS
- Interpolate missing observations





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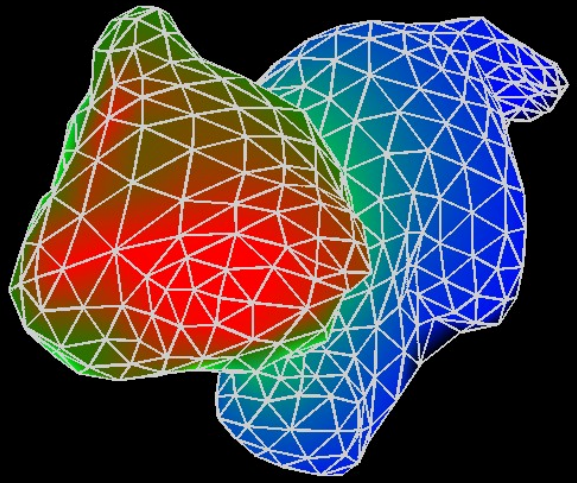
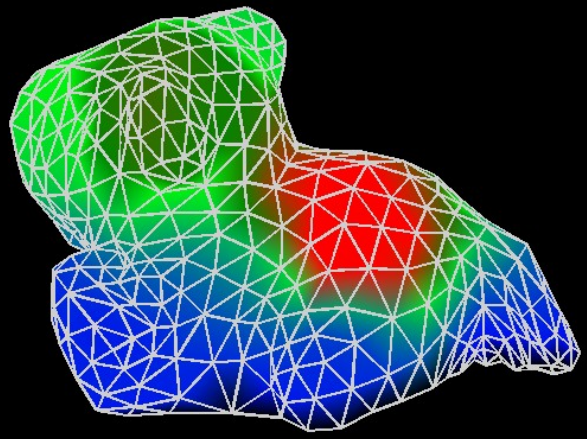
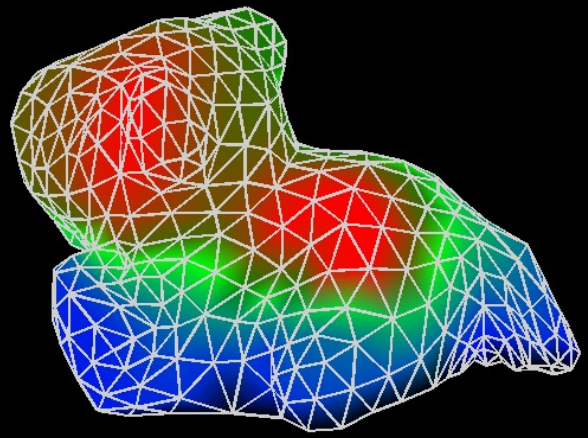
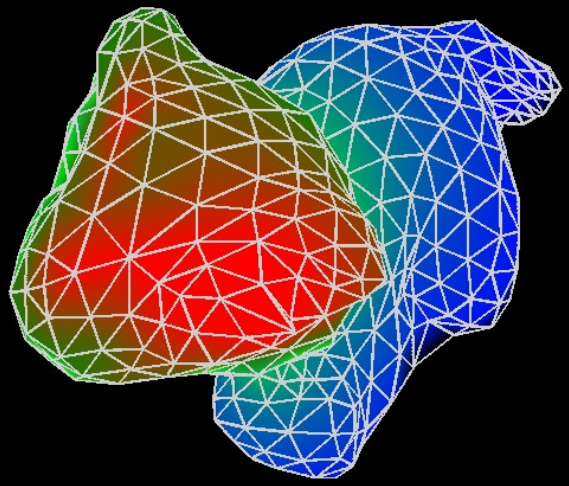
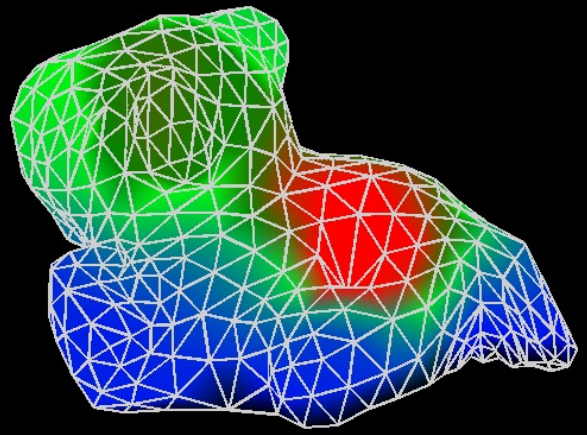
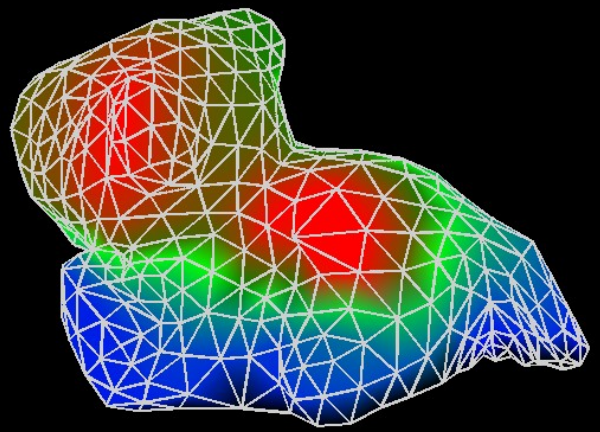




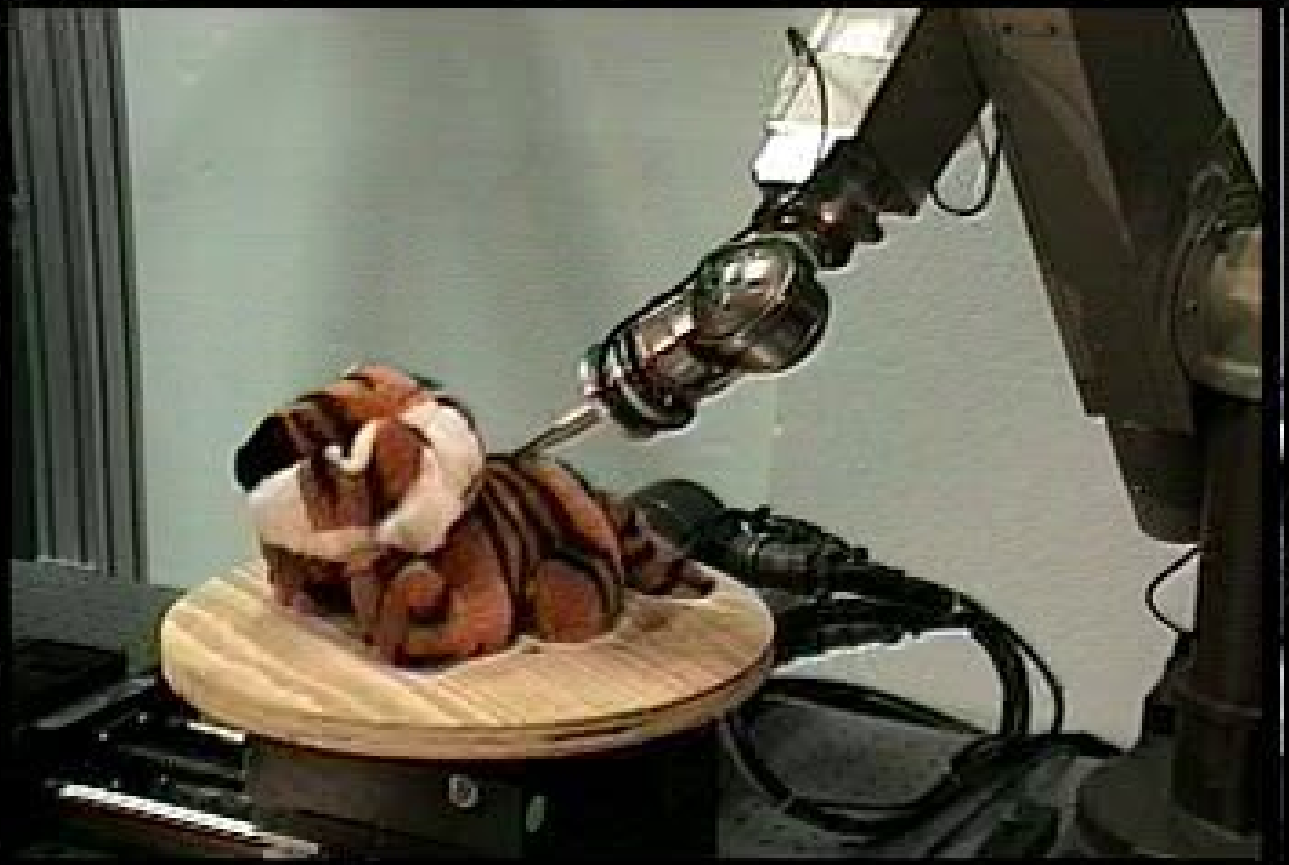








Results



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Interactive Rendering Demo

Rendered using capacitance matrix algorithm
with haptic force computation at 1KHz
[JamesPai99, JamesPa

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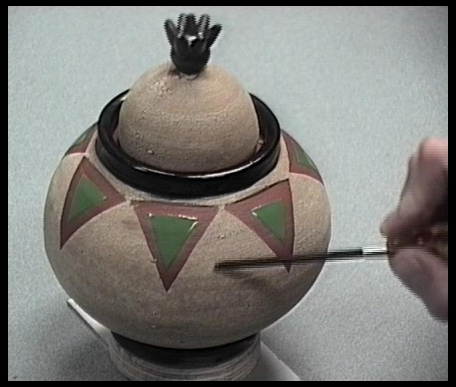
Scanning Contact Texture



What is Contact Texture?

- **Physical parameters relevant to haptic texture perception** [Lederman Klatzky]
- **Texture = friction + roughness + …**
- **Model should support fast simulation for haptics (1 KHz) and audio (44.1 KHz)**

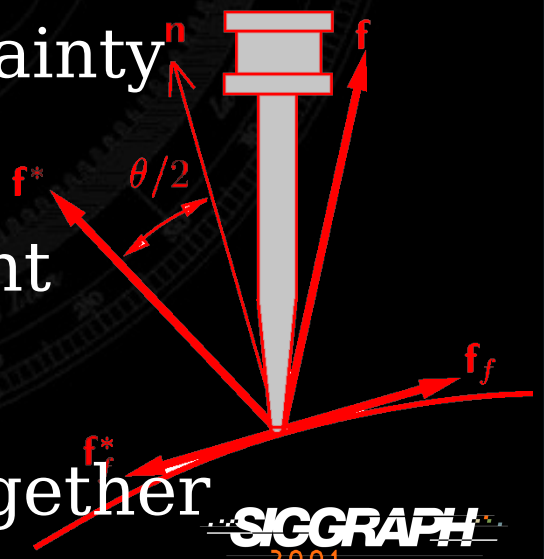
Friction

Model: Coulomb Friction $f_t = -\mu \; | \; f_n | \; \mathbf{u}$

Measurement:

- Easy for small sample
- Hard for general object: uncertainty in surface normal, adaptation
- We use differential measurement technique for robust estimation

Estimate: normal and friction together



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Roughness

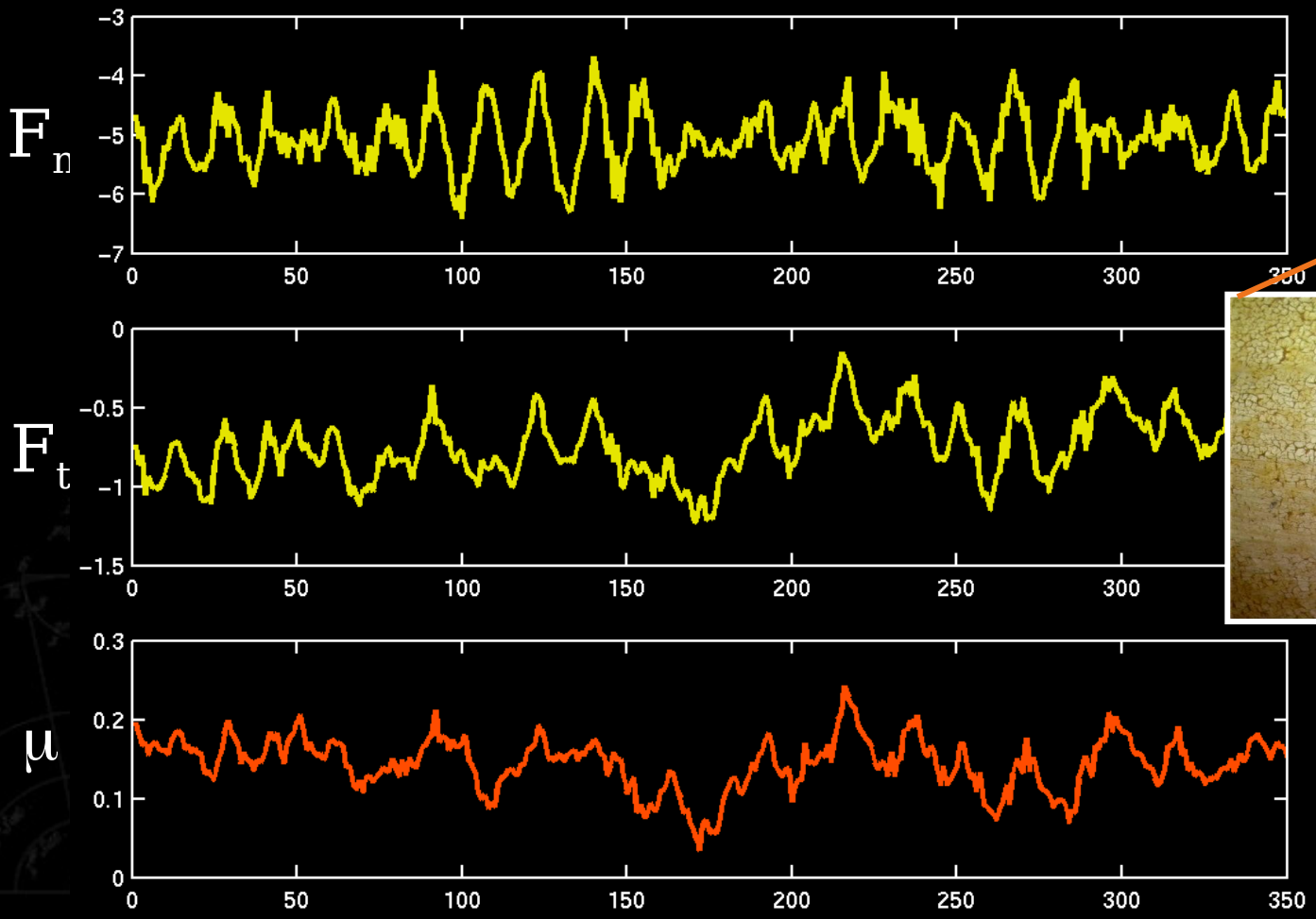
Traditionally ≈ small scale variation in surface geometry

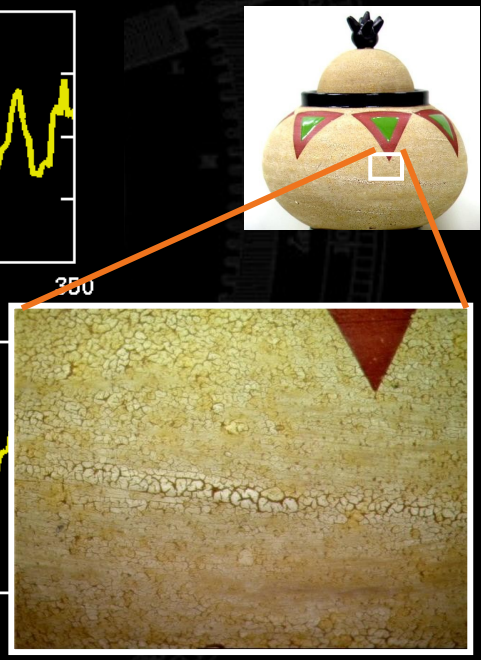
Our model: small scale variation in friction

- Equivalent to traditional model, for frictional contact
- Unifies friction and roughness haptic rendering

Statistical process models effective for many surfaces **[Thomas 82, Perlin]**

Example: Clay Pot





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Roughness

Model structure: AR(p) autoregressive model

- Captures randomness plus periodicities
- Small p sufficient for most surfaces

Estimate parameters: using covariance method

Rendering: Discrete convolution

Extremely fast and simple

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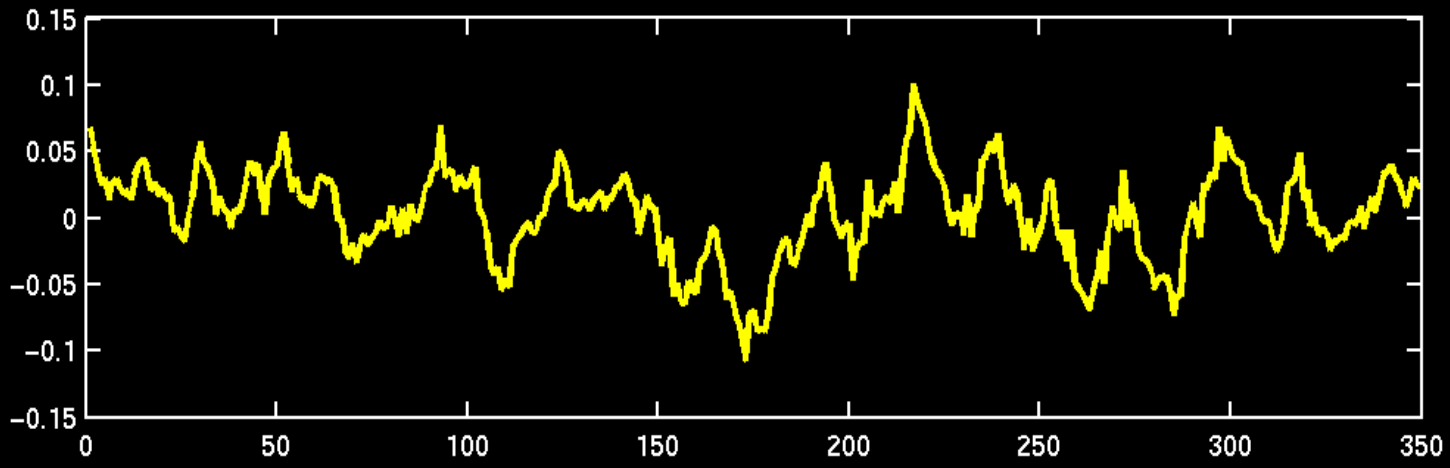
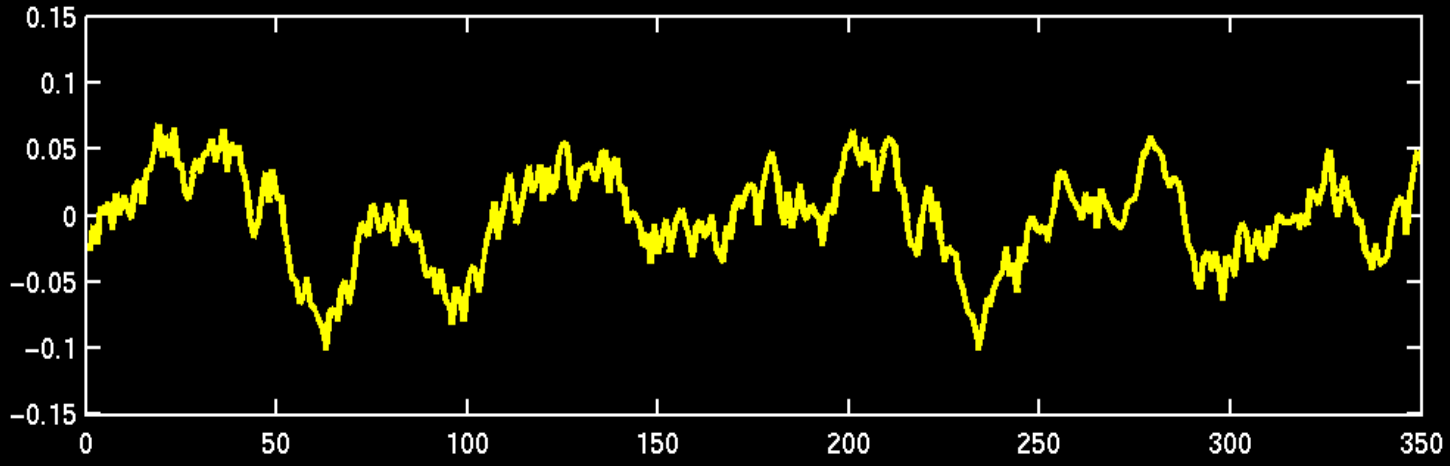
Real vs. Simulated Clay Pot

Real μ

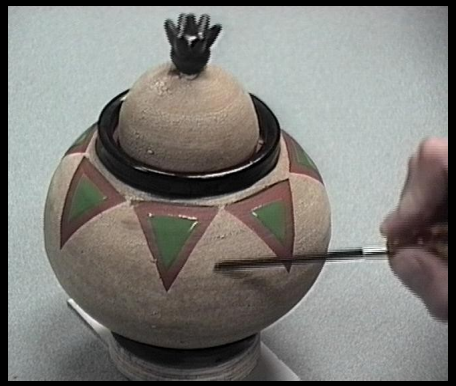


Sim μ



Scanning the Clay Pot

Scanning Contact Sounds



Contact Sounds

- Provide cues of contact shape, location, force, and object material
- “Foley sounds” in radio and cinema
- Integrated with Simulation and Interaction [O’BrienCookEssl, DoelKryPai, Friday]
- and room acoustics [e.g., Tsingos et al., Friday]

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Model Structure

Modal Synthesis [e.g., Doel&Pai 96-01, Cook 96]

Impulse response model at boundary vertex x

$$\sum_{i=1}$$

f_i **is frequency of a vibration mode**

d_i **is frequency-dependent damping**

Texture map $a_i(x)$ **onto object surface**

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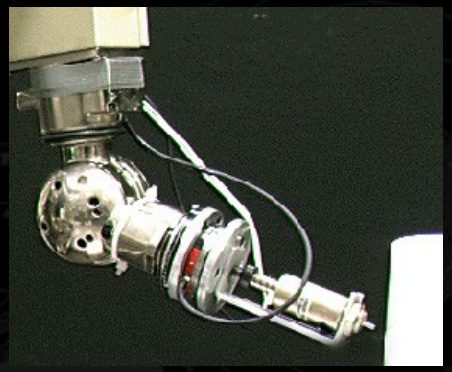
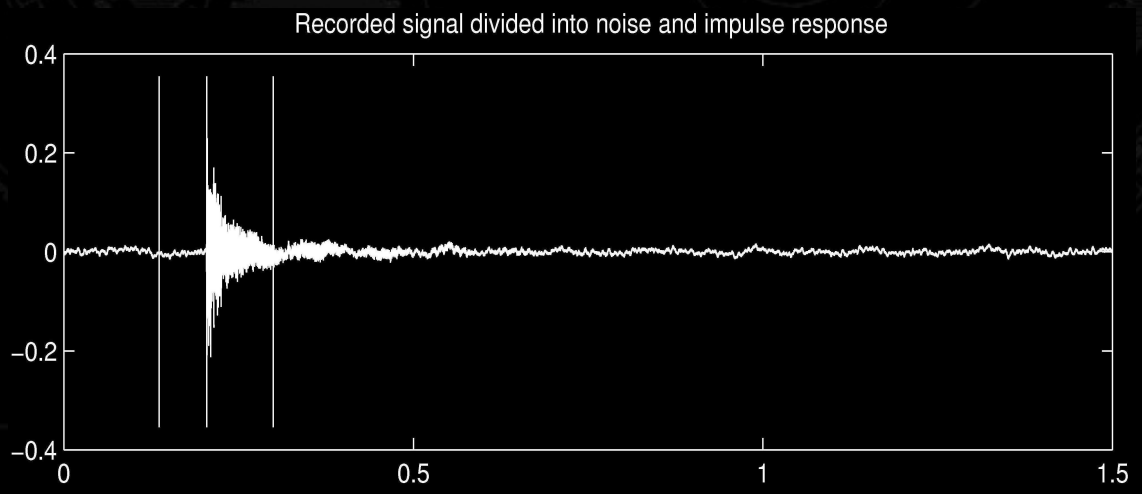
Measure Impulse Response





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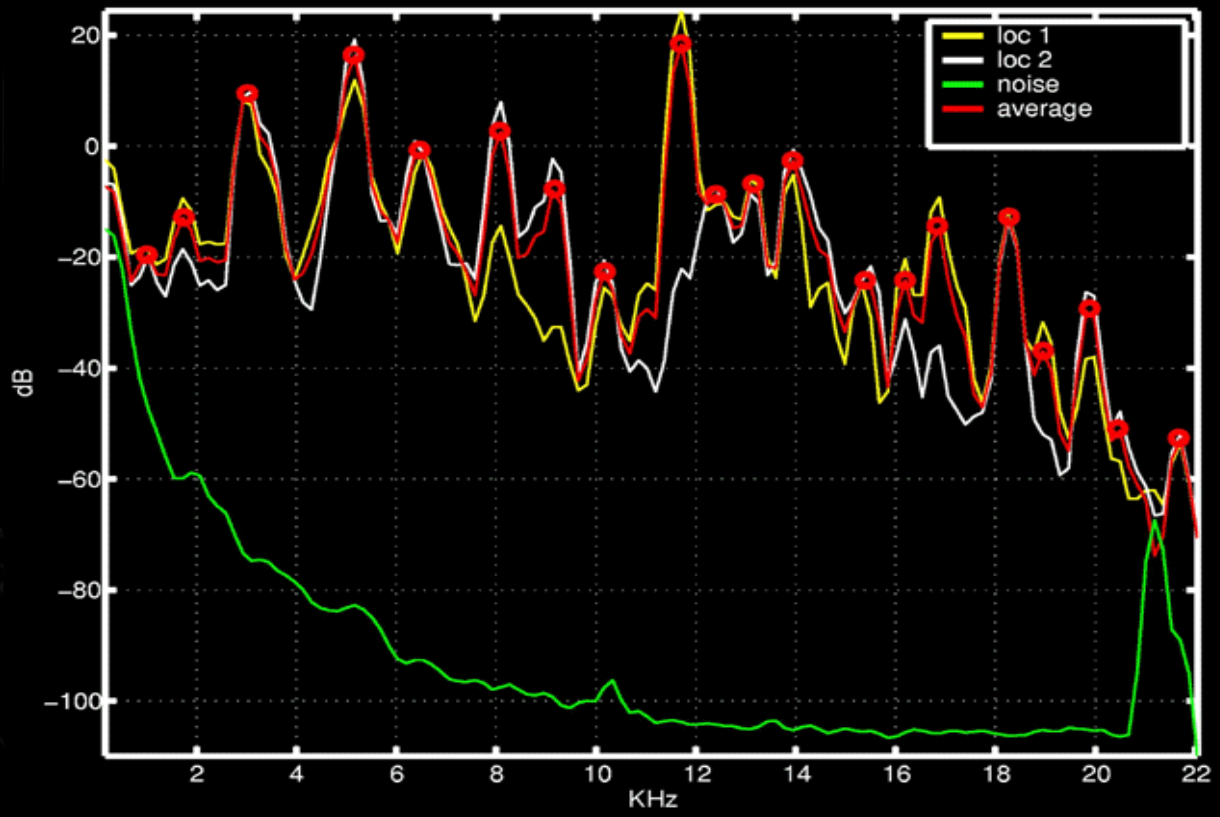
Estimate Parameters

First estimate modal frequencies f_i



Refine frequencies + estimate a_{ik} , d_i

[SteiglitzMcBride65, BrownPuckette93]

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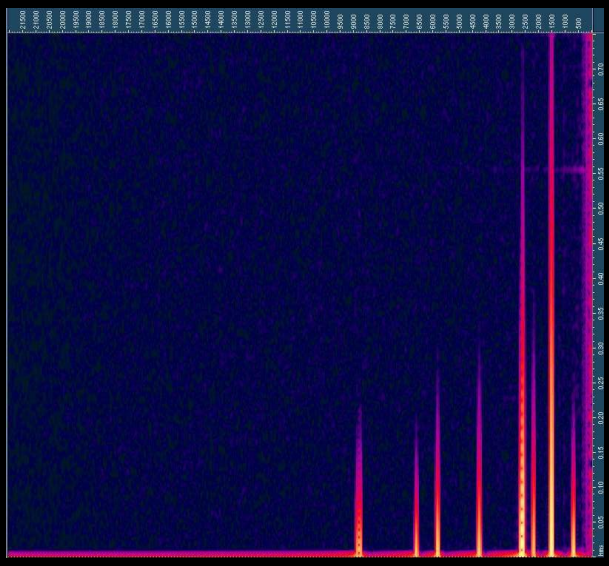
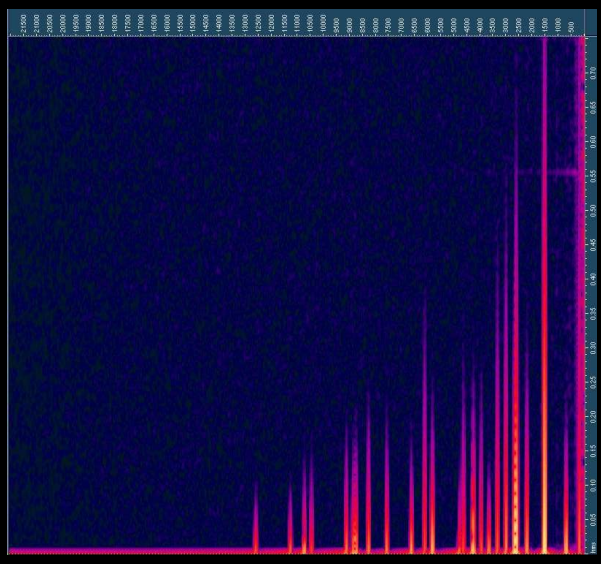
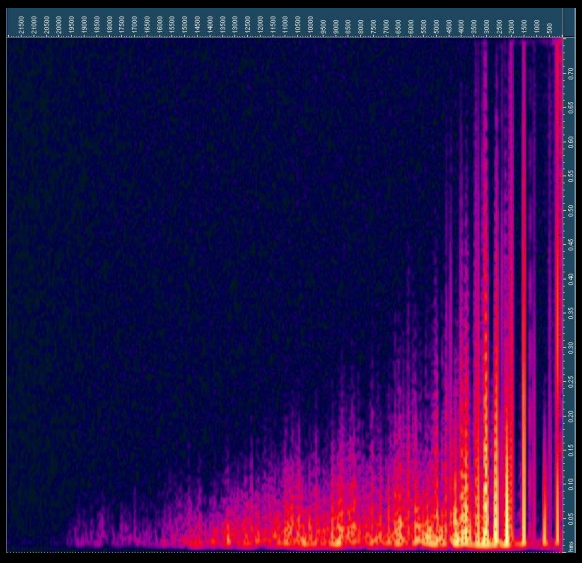
10 modes

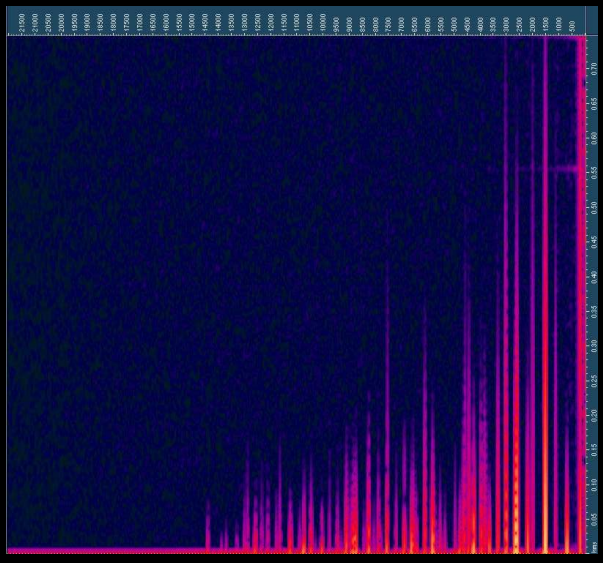


30 modes





original



90 modes

Rendering

Generate contact force at audio rates

- depends on contact texture, nominal force, and velocity
  [see DoelKryPai paper on Friday]

Convolve with audio impulse response

- efficient using modal resonator filter bank (4 flops/mode/sample)
- smoothly interpolate audio parameters $a_i(x)$ from mesh vertices

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Scanning the Clay Pot

Video

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Conclusions

It is now possible to scan multi-modal models of contact interaction behavior

Scannable behavior includes

- deformation (visual and haptic)
- friction and roughness texture
- sound response

Can be automated with ACME, a robotic measurement facility

The Future?

Multi-modal virtual environments, with visual, auditory, and haptic interaction

A digital "Model Foundry"

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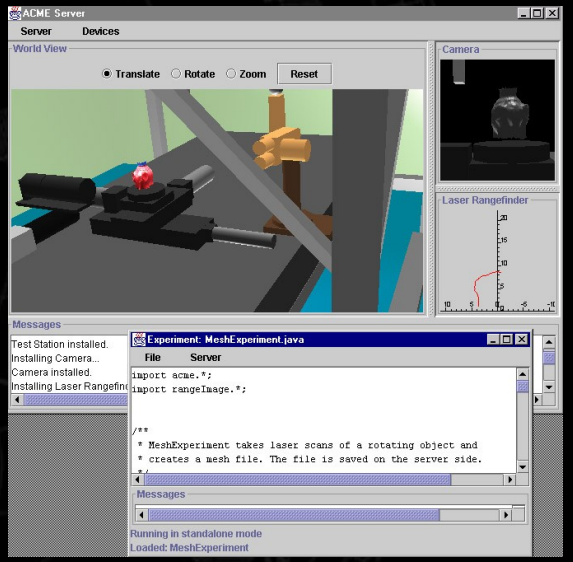
Demos at the CAL

- Telerobotics: measure an object in Vancouver with ACME
- Interaction with scanned models using force feedback and sound
- Times:

  Wed & Thu 4 - 6 pm

  Thu & Fri Noon - 2 pm



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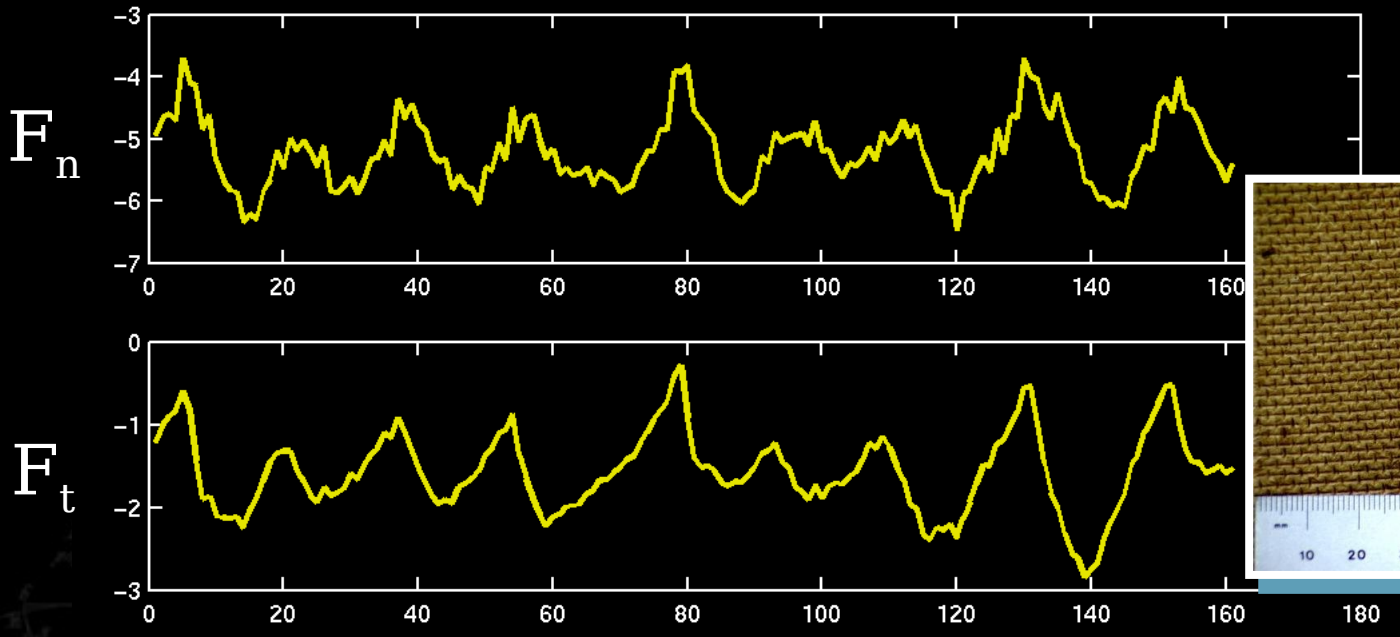
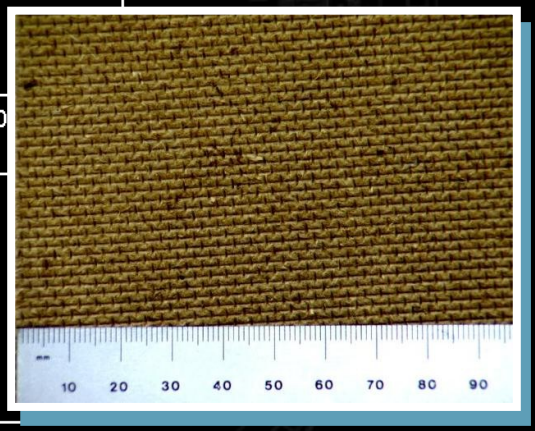
Example: Masonite





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